ENERGY, NATURAL RESOURCES AND RESEARCH IN AGRICULTURE

Effects on Economic Growth and Productivity for the United States

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Abstract

Farm use of electricity and petroleum fuels, public investment in conservation and natural resources, and agricultural research and extension are discussed as factors in economic growth and production efficiency in American agriculture. The analysis covers mainly the 44 years from 1929 to 1972 but also gives some data for the period from 1948 to 1972. Growth and efficiency effects are determined from production functions that consider the three factors to be auxiliary inputs to farm labor, capital investment, and farmland. Gross farm product (GFP) data published in the national income and product accounts of the United States are the measure of total farm output and real growth. The productivity measure is the ratio of an index of total output over an index of all farm inputs as periodically published by the Economic Research Service.

The effects of the three auxiliary inputs and various basic inputs on total farm output and efficiency are quantified as 'partial' rates of growth or decline in output or productivity. A partial rate is the product of the average annual rate of change in the employment of a specific resource input and its unit effect on output or efficiency.

Results indicate that energy use in agriculture has contributed modestly to economic growth in agriculture. It has had a somewhat greater positive effect on the efficiency of resource use on farms. Increased energy use accounted for perhaps 6 percent of the tendency for agricultural output to increase from 1929 to 1972, and for 15 percent of the tendency for productivity to increase.

Results for public resource development and conservation indicate that it has contributed positively but in a minor way to economic growth in agriculture. It has tended to depress overall efficiency in resource use. It appears to account for from none to 10 percent of the tendency for growth, but for from none to perhaps 1/3 of the tendency for efficiency to decrease.

Agricultural research and extension results indicate that it was the most important factor in real farm output in the United States having increased at a net rate of 1 percent per year over the period 1929-1972 and in farm productivity having increased by 1.75 percent per year. Research and extension activities explain about 80 percent of the tendency for growth from 1929-1972, and from 60-70 percent of the tendency for increased efficiency.

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Purpose and Background

This paper discusses the importance of the farm use of electricity and petroleum fuels, public investments in agricultural conservation and natural resource development, and public investments in agricultural research and extension in explaining economic growth in the farm sector of the United States economy. It also assesses their importance in explaining increased efficiency in the use of resources at the farm management level. The analysis covers the 44 years from 1929 to 1972 and the 25 years from 1948 to 1972, using highly aggregative but complete annual data. Indicative effects of energy use, natural resource investments, and research investments are determined with production-function estimators that consider them to be auxiliary to farm labor, buildings and equipment, business inventories and farmland.

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The paper does not review the energy situation or any other resource situation in any great detail. Gavett (9) has discussed fairly completely the current energy situation as it involves agriculture. Some statistics on electricity and petroleum consumption for selected years between 1929 and 1972 are in table 1.[1/] The use of energy resources for agricultural production is undoubtedly an important policy question and requires rather thorough economic analysis, particularly if controls on their use are contemplated.

The Secretary of Agriculture would prefer that energy use in agriculture not be curtailed.[2/] He alludes to the importance of agricultural exports as a particular offset to heavier reliance on imported crude oil and a bright spot in the generally unfavorable U.S. trade balance. This presents some serious policy and political challenges for agriculture. Efficiency considerations and alternatives like those of Berg (3) and Perelman (12) will need to be examined, and in the economic-environmental context in which energy supply confronts the public at large. This is one reason for looking also at public investments in agricultural conservation and natural resource development for their effects on economic growth and farm production efficiency. Data for selected years since 1929 are also in table 1. Another is the nonexistence, to the author's knowledge, of definitive information on the relationship of public natural resource development, broadly conceived, to national agricultural growth

1/ Tables are grouped at the end for easier reference and comparison.
2/ Earl L. Butz. Expanding energy for national growth. Address by the Secretary at a Special Conference on Energy, Chamber of Commerce of the United States. Washington, D.C. May 2, 1973.

and in comparison with conventional farm inputs. Holloway provides some useful information like this for a particular broad region, but other regional resource studies have tended to de-emphasize the importance of growth in the agricultural sector.[3/]

Research and extension are analyzed as a third auxiliary variable in growth and productivity because they, in addition to being in budgetary competition with conservation and development, are widely believed to have significantly changed the mix and quality of farm resources and enhanced efficiency. Griliches (10), Evenson (6) and, more recently, Ayer and Schuh (1) have led in isolating and quantifying the benefits of research and extension. Table 2 gives State and Federal research and extension expenditures for selected years starting with 1929.

While not of the same high order of magnitude as Griliches' or Evenson's estimates of marginal returns to research, my results also show substantial returns. But I place less emphasis on converting the benefits to dollars and prefer to show how research and extension are associated with real growth and efficiency in the agricultural economy. Given Wade's recent uncomplimentary 'evaluations' of the state of agricultural and agricultural economics research management in the United States (23), there may be wider interest in examining the real social substance and benefits of all types of agricultural research and extension.[4/] Information on the change over time

3/ Holloway, Milton L. 1972. A production function analysis of water resource productivity in Pacific Northwest agriculture. Ph. D. thesis. Oregon State University Library, Corvallis. 205 pp.
4/ The Wade articles draw heavily from the Report of the Research Advisory Committee to the U.S. Department of Agriculture, also called the 'Pound Report.' Available for $4.85 (+ $9.00 for appendices) from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22151.

in the benefits of public research and knowledge dissemination is definitely lacking and not easily developed but would seem elementary and vital for even marginal let alone any wholesale redirections of research or extension programs.

Economic Growth and Productivity Measures

In studies of economic growth and efficiency there must be a clear understanding of what is being measured. The concepts of economic growth and economic efficiency are related but not synonomous, even at a national or macro level. Growth has occurred without maximum efficiency in resource use, and efficiency with respect to one measure of output can be changing more rapidly or slowly than with regard to other measures. Much of economics is concerned with describing these differences, analyzing why they occur, and finding out what can or should be done to accelerate or control change to meet certain policy objectives.

Total output and economic growth

In the national income and product accounts of the United States maintained by the Department of Commerce (22), total farm output is defined as Gross Farm Product and, for some purposes, as National Income originating in the farm sector. Subsidies, for example, are regarded as part of National Income. But they are excluded from Gross Farm Product (GFP) and thence from the Gross National Product (GNP). Conversely, capital depreciation and farm property taxes are not counted in National Income but are included in GFP and GNP. Other peculiarities of national bookkeeping could be given. A key point is that National Income for the agricultural sector is all income earned for providing agricultural goods and services through the economic system while

GFP represents the total market value of that output.

Further, GFP as well as GNP are real constant-dollar measures of production when deflated for price changes. In 1972 or current dollars, for example, GNP for the United States was about $1,152 billion while GFP was $33.4 billion. In 1958 or deflated dollars the GNP in 1972 was $789.7 billion and the GFP was $23.3 billion. The National Income, in theory, is the summation of and a superior concept for analyzing factor returns. But it normally is not deflated to constant dollars. This is because many forms of personal income and, certain items not constituting personal income but that are part of the National Income, like personal contributions for social insurance, are not easily adjusted for price level changes. Consequently, National Income data are not very suitable for measuring real economic growth.

In this analysis the GFP data published in the national income accounts are used as the measure of total farm output. This permits comparisons of growth in the farm sector versus other sectors and in the economy as a whole. The price base is the year 1958. Increases (decreases) over time in real GFP are considered to constitute economic growth (decline) in agriculture. The annual percentage increase or decrease in GFP is the rate of growth or decline.

A few statistics will help stress the concept of growth in mind. In 1929 real GFP for the United States was 17.0 billion or about 8 percent of the real GNP (table 3). By 1948 the annual GFP had increased 12 percent--to $19.0 billion. In 1972 it was $24.7 billion. This was 45 percent more than in 1929, 30 percent more than in 1948, but was down to 3 percent of GNP. The net rate of annual growth of GFP was close to 1 percent for the period 1929-1972 and about 1.12 percent for 1948-1972. Net growth rates for the entire U.S. economy were 3.2 percent between 1929 and 1972 and 3.8 percent between 1948 and 1972.

Farm production efficiency

Most economic efficiency or productivity data published for the general economy and its major sectors are labor-oriented. Differences over time and among producing sectors are expressed in national and sectoral accounts as ratios of total real output per unit of labor employed. While they permit some useful comparisons of efficiency over time and in different industries, the ratios do not show the returns to labor as such but give the average product of labor combined with capital and other inputs. Productivity ratios that weight the various inputs proportionately with their employment are more accurate and more flexible indicators of efficiency.

The productivity measure used in this analysis is the ratio of the index of total farm output over the index of all farm inputs, developed and regularly provided by the Economic Research Service for official reports on the economy (19). Total farm output in the calculation is similar but not synonomous in meaning or size with GFP as discussed above. The ERS input index incorporates inputs at their annual factor costs to farmers and not particular physical quantities. It does not include public expenditures for conservation, resource development, and research or extension, although these items are reflected to a minor degree in property taxes. The ERS productivity index thus measures economic efficiency in the use of resources from an internal farm management viewpoint more than from a national economic or public viewpoint.

Compare the indexes of output per unit input in table 3. On the ERS index, farm production in 1972 was more than twice as 'efficient' as in 1929 and nearly 50 percent more efficient than in 1948. Computed net rates of productivity increase were 1.75 percent per year for the period 1929-1972 and 1.6 percent for the period since 1948. Common explanations for these

substantial productivity gains deal primarily with the exodus of farm operators and farm laborers from agriculture, the heavy substitution of capital for labor, and the adoption of advanced technologies.

Resource substitution and auxiliary inputs

The directions of basic input changes, historically, are apparent in table 3. But substitution effects on productivity or, for that matter, on total output, are quite unclear from the data. For example, the total real investment in farm capital increased an average of 1.2 percent per year from 1929-1972 and about 1.5 percent from 1948-1972. The increase in capital has been concentrated in farm equipment, although considerably less so since 1948. Total labor employment decreased an average of 3.3 percent per year between 1929 and 1972. The average decrease since 1948 has been 4.2 percent. In short, the reduced employment of labor, especially hired workers, has accelerated since 1948 while, in total, capital investment has picked up by about the same ratio. Increased investment in farm equipment has slowed down. Investment in nonresidential structures and business inventories has tended to increase more rapidly from year to year. Livestock account for most farm business inventories.

Such countervailing trends, in addition to showing the complex dependence of changes in total farm output and farm production efficiency on the changing level and marginal returns of basic farm inputs, suggest that the employment and productivity of certain 'auxiliary' factors, including public inputs to the production process, also may explain tendencies for output or productivity to increase and decrease over time. Three 'auxiliary' inputs are considered here: Annual farm energy expenditures, public investment in agricultural resource development and conservation, and public investment in agricultural research.

Summary data for auxiliary inputs are given in table 3 for comparison with basic farm inputs. Details are in tables 1 and 2. The energy expenditures are a variable operating cost but represent purchases from other business units and are netted out of total output or gross farm product (GFP). So strictly speaking, there is an element of double-counting in including them on the input side, although variable expenses have been treated as a separate input in many other growth studies and do not pose double-counting in analyzing efficiency. The significance of the energy, natural resource, and research expenditures in table 3 is less in their magnitude in relation to basic inputs than in their rates of annual change and substantial differences in the rates for the periods 1929-1972 and 1948-1972.

Statistical Approach and Methods

The analysis employed familiar Cobb-Douglas production-function estimators for total farm output in GFP terms and, alternatively, for farm productivity on the ERS index. The estimators differed with respect to: (1) The degree of input aggregation; (2) the exclusion or inclusion of the three auxiliary factors of energy, natural resources, and research; and (3) including or not including factors in aggregate demand like total population, per capita income, and agricultural exports (see table 3). The latter distinction was to provide a comparative check on the predictive power of the different 'supply' or input-based estimators.

The analysis employed national time-series data for the period from 1929-1972 (N = 44 years) and for the subperiod from 1948-1972 (N = 25 years). Data sources are referenced in table 3. Complete definitions are in the references and need not be repeated here. A comment on the four capital categories, however, is that they match the components of gross private

domestic investment set forth in the national income and product accounts. Another point is that the capital is valued on an acquisition-cost basis rather than on a replacement-cost or net depreciated basis. This recognizes that depreciation allowances count as gross output in the national accounts and so must appear on the input side also.

Unfortunately, the land investment could not be figured the same way. The real investment shown in table 3 for farmland is essentially the current real estate value in 1958 dollars, but excluding all farm buildings. They could be valued like durable equipment on an accumulated-acquisition-cost less discard basis.

Farm energy expenditures in table 3 are annual expenditures converted to 1958 dollars. Public natural resource investments include accumulated Bureau of Reclamation expenditures for western irrigation development and primarily agricultural multipurpose projects, accumulated Soil Conservation Service expenditures for watershed development and protection projects in all States, and annual State or Federal conservation expenditures, all in 1958 dollars. For this analysis, the public agricultural research and extension investment is figured as annual expenditures in 1958 dollars accumulated for the prior 20 years. Additional historical data on these auxiliary agricultural inputs are in tables 1 and 2.

In addition to descriptive importance the annual rates of change in resource employment in table 3 have another purpose in this analysis. Combined with elasticities they are used to impute growth or productivity to variations in particular resource inputs. Average annual rates of change (r) for any input X were computed by least squares methods from the equation $X(T) = A(1 + r)^{T - T_b}$. Its linear equivalent is $\log X(T) = \log A + (T - T_b) \log (1 + r)$, where T_b is the base year (taken as either 1929 or 1948), and

where X is the quantity of the input used in year T. Taking T to be the year - 1900, it thus takes values from 29 to 72 for the period 1929-1972 ($N = 44$) and from 48 to 72 for the period 1948-1972 ($N = 25$). In this case the constant term A is either $X(29)$ or $X(48)$, depending on the period under study.

Interpreting time series estimators

The classic Cobb-Douglas production-function estimator is written $Y = A X_1^{b_1} X_2^{b_2} \ldots X_n^{b_n}$, where Y is the output (GFP) or productivity variable being estimated in relation to the magnitudes X of n different input or independent variables. The term A is a mathematical constant and the $b_1, b_2, \ldots b_n$ are regression coefficients, in this case elasticities, that weight the effects of particular independent variables in determining the value of Y.

A modified or dated estimator is used for this exercise. It is written $Y = A (1 + r)^T X_1^{b_1} X_2^{b_2} \ldots X_n^{b_n}$, where T denotes time or the year as specified above, but where r is now the underlying trend or the compound rate at which Y changes over time regardless of how the input or X values vary. Burns (3), Evenson (6), Smith (15) and others allow for persistent time-associated changes in this fashion and usually, on *a priori* grounds, equate time trend with technological change. While the assumption has some logical validity and tends to be verified in some of my results it was not considered essential to the analysis. For example, what would explain a negative 'trend' during a period when important technological advances were known to have occurred? Also, what interpretive loose ends are created by proceeding as if technological change has been gradual at the constant rate r?

A more fundamental reason for inserting the time variable in the estimators of output and productivity is that variations in X for the n inputs are converted thereby to departures from their own trends. An equivalent alternative is to omit the time term $(1 + r)^T$ but to convert each of the time series observations for X and Y to deviations from their own trend. But as Tintner demonstrates (18, p. 301), this is needlessly cumbersome and inferior to directly introducing the time term and so not having to transform the actual time series data for X or Y . Tintner credits the proof of this very useful theorem and tactic to Ragnar Frisch and Frederick V. Waugh. It appeared in 1933, in the first volume of Econometrica (8).

Subjecting time series information to scientific analysis and inferring cause-effect relationships remains one of the most complex and interesting areas of economics and statistics. The usual tests for statistical significance apply only infrequently and under very restrictive conditions. Observations in a series may be internally correlated with each other (serial or autocorrelation). Two time series on a pair of independent variables may themselves be so highly correlated that the predictive effects of neither variable can be determined with any precision (intercorrelation). For other specifics and guidelines see the texts of Davis (4) and Fox (7), Tintner's various contributions (16, 17, 18), and an instructive booklet by Quenouille (13). In particular, Davis recounts how the study of time series observations originated in astronomy where, despite the dominance of the Sun in explaining planetary motions, one equation for predicting the motion of the Earth's moon goes on for 170 pages (4, pp. 1-7). This is a humble lesson for economics, where one factor rarely explains the movements of any time series and where few observations may exist for the particular series in which we are interested.

Alternative estimator forms

All estimators for Y in this analysis were derived empirically by the usual least-squares techniques. They reduce to the linear function $\log Y = \log A + \log (1 + r)\ T + \sum_{1}^{n} \left[b_i \ \log X_i \right]$. This means that output or productivity in deviations from trend were linearly associated with deviations from trend for each of n relevant predictors. Five different formulations were tested. All five considered total farm output or GFP. Farm productivity on the ERS index was considered in the first four. The types largely conform to the resource classification of table 3. They are outlined below with regard to the variables considered relevant, but not necessarily significant, in explaining the growth of output and changes in farm production efficiency.

1. Inputs aggregated without auxiliaries: Y = total output or productivity. Independent variables (4) include time, total labor, total capital and farmland.

2. Inputs aggregated with auxiliaries: Y = total output or productivity. Independent variables (7) include time, total labor, total capital, farmland, farm energy expenditures, natural resoure expenditures, and research and extension expenditures.

3. Inputs segregated without auxiliaries: Y = total output or productivity. Independent variables (8) include time, family labor, hired labor, nonresidential structures, residential structures, producers' durable equipment, business inventories, and farmland.

4. Inputs segregated with auxiliaries: Y = total output or productivity. Independent variables (11) include the same 8 included in type 3 plus farm energy expenditures, natural resource expenditures, and research and extension expenditures.

5. <u>'Demand' estimator</u>: Y = total output only. Independent variables (4) include time, total U.S. population, per capita real income, and agricultural exports.

Statistical criteria and correlations

The five types of production-function equations outlined above expand to 18 estimators derived through multiple regression procedures--9 for each of the time periods 1929-1972 and 1948-1972, 5 for total output and 4 for productivity. Each final estimator 'structurally' included, from among the relevant independent variables listed for its type, only those variables (significant predictors) reducing unexplained variance by at least 2 percent. This means that partial correlation coefficients were required to be at least $\pm$ 0.14. The partial correlations for nearly all the significant predictors were actually much greater than this minimum. Tests for the significance of 't' values were not applied, although here again, virtually all the 't' statistics would test out at better than 95 percent and none at less than 60 percent.

The general predictive power of an estimator is measured by the coefficient of multiple determination or R^2, which must exceed R^2 for any single variable. This elementary condition is particularly important in regressions involving time series data because of a notorious tendency for different series to move together or oppositely and be highly correlated--statistically speaking. There may be no causal explanation whatever.

In predicting U.S. agricultural output or productivity with no concern for developing structural information on particular predictors, time alone and almost any of the basic inputs, auxiliary inputs or demand factors would

serve quite adequately and about equally well for most purposes. This is evident in table 4, which gives the simple time series correlations for the period 1929-1972. Only farmland inputs were, linearly in logs, poorly correlated with output, productivity, and time.

Note especially in table 4 that time series for all inputs other than land and inventories are correlated more with time alone than with either output or productivity. The need to separate out the time trend is obvious, regardless of whether we call it technological change. A useful first step is to examine the simple correlations of deviations from trend in the respective explanatory variables with trend deviations for output and productivity. These correlations are also given in table 4. They clearly show, when compared with simple correlations between annual time series, a general weakening of the apparent statistical relationships between resource use and farm output or productivity. However, the deviation correlations are still only loose indicators of how output or productivity might have varied from 1929-1972 with respect to all resource use or demand factors. They do help isolate strong direct associations, like the 0.74 correlation between business inventories and output. But they say nothing about the perhaps more important or offsetting indirect associations. This explains the emphasis in the analysis on partial coefficients of correlation. They indicate the degree of association between a pair of variables like labor and output, after removing the effects of other variables like capital or time on either labor or output, or on both.

Particular cases and estimators

Space does not permit showing detailed results for each of the five output and four productivity estimators derived for the period 1929-1972 and

also for the period 1948-1972. The primary focus from here on will be the estimators (type 4 above) in which basic farm inputs were segregated and which included the auxiliary inputs of energy, public natural resources investments, and research. This type of estimator turned out superior to any of the others (maximum R^2 and minimum standard errors) in predicting both output and productivity and for both time periods. Actually, the R^2 values for the 16 estimators were all relatively high and comparable (range 0.918 to 0.994) and significant at at least a 90 percent probability level. Standard errors of estimate were fairly low (range 0.007 to 0.023--in log Y). Some inter-correlation was evident in all estimators but did not appear serious. Auto-correlation tests, using Durbin-Watson criteria, were either inconclusive or showed no evidence of autocorrelation. An exception was the aggregative estimator for output from 1948-1972 with the auxiliary inputs excluded. Here the test showed strong positive autocorrelation. The asserted superiority of the estimators involving disaggregated inputs and the auxiliary variables invokes a conservation-of-information concept, in that a maximum number of 'relevant' independent variables could also be identified as being significant predictors of output or productivity.

Some Notes on Demand

Before proceeding further some brief comments are in order concerning the 'demand' estimators of output for 1929-1972 and 1948-1972. Significant output predictors for 1929-1972 on the demand side included total population, per capita real income, and time trend ($R^2 = 0.845$). The time trend was slightly negative. Partial correlations with gross farm product (GFP) were 0.31, 0.35, and -0.17, respectively. The 1929-1972 elasticity coefficients turned out to be 0.823 for total population and 0.235 for per capita real income.

For the period 1948-1972, two significant demand factors in GFP were total population and agricultural exports ($R^2 = 0.936$). The average net effects of exports appear to have been negative, however. There was no significant underlying time trend and per capita real income also drops out of the estimator. Partial correlations were 0.85 for total population and -0.43 for agricultural exports. Remember, however, that these are average effects for the 25 years since 1948. Effects for any portion or particular years of this period could be totally different. The recent surge in export demand for U.S. farm products is especially indicative of real growth because it principally involves grains, oil crops, and other commodities for which we have had excess capacity problems.

Estimating Rates of Growth

During the 44-year period 1929-1972 total farm output for the United States increased in real terms at an average rate close to 1 percent per year. Farm production efficiency on the ERS index rose by 1.75 percent per year. Increases for the 25 years from 1948-1972 ran about 1.2 percent for GFP and 1.6 percent for farm productivity. These rates (r_y) can be approximated from the simple relations $Y(1972) = Y(1929)\ (1 + r_y)^{43}$ or $Y(1972) = Y(1948)\ (1 + r_y)^{24}$, where Y represents either total output or productivity for the years indicated. The Y's are taken from the statistically-derived production-function estimators in which basic farm inputs were disaggregated and which considered the auxiliary farm energy, natural resource and research inputs.

Figured in the manner above, the rates r_y do not differ greatly from the alternative of simply using published observations on output or productivity for values of Y. But the alternative abstracts completely

form the forces that influence growth. The resulting estimates of r_y, while useful for description, are analytically sterile and so have little use for agricultural policy.

Partial rates of growth

Consider again the rates of growth r_y determined from production-function estimators of output or productivity. In reality they are net rates of growth that reflect the balance between concurrent tendencies for growth and decline. In the analysis the tendencies are quantified--as 'partial' rates (r_x) of growth or decline in output or productivity associated with the changing use of resources over time. The partial rates r_x are the product of (a) average annual rates of change in the employment of specific resources, and (b) their elasticities or unit effects on output or productivity. A partial rate measures the change in output or productivity associated with a particular resource, separating out (c) the change associated with all other resources, and (d) any significant time trend.

The sum of all positive partial rates and any upward residual time trend is called the general tendency for growth. The converse tendency for decline is the sum of all negative partial rates and any negative time trend. The difference between the two general tendencies gives us the net rate of growth or decline. The procedure to this point is similar in concept to the methods used by Denison (5) in his comprehensive and highly regarded studies of U.S. economic growth. His analysis of growth examines index number movements more than empirical production functions. Mathematically, the procedure here is merely a manipulation of the production function as an input-output relation. Smith gives a more thorough explanation of functional estimators and also an excellent review of Denison's work and other methods for analyzing growth. (15, pp. 405-410 and 423-428).

Importance of specific factors in growth or decline

The relative importance of each basic and auxiliary input as a determinant of economic growth and advances in farm efficiency is assessed from its respective partial growth rate. An input or resource for which the partial growth rate is positive is considered to have contributed to the general tendency for growth, and in proportion to the magnitude of the partial rate. The rate will be positive if the average annual rate of change in employment of the resource during a given period (1929-1972 or 1948-1972) and the corresponding elasticity coefficient are both positive, or, both negative. The partial rate will be negative if either the annual rate of change in employment or the elasticity coefficient is negative. A resource for which the partial growth rate was negative was considered to have contributed to the general tendency for decline, and in proportion to the absolute size of the negative rate.

If significant, time trend was similarly quantified as a partial rate and for its importance, except that the 'partial' rate in this case is the rate r in our functional estimator $Y = A(1 + r)^T X_1^{b_1} X_2^{b_2} \ldots X_n^{b_n}$. The term $\log(1 + r)$ is the regression coefficient for T.

Preliminary Statistical Findings

Statistical details of the analysis confined to disaggregative estimators of output and productivity changes are in tables 5 and 6. The data should be fairly self-explanatory in view of the procedures already discussed. Table 5 (part A) first repeats simple correlations for agricultural research and extension, for annual time series and trend deviations, to illustrate how multiple regression estimators can disprove entirely any explanations for change based on simple correlations.

General characteristics of estimators

These are given in table 5, part B. Judging from the R^2 and standard errors, overall prediction accuracy is high, but higher with respect to predicting farm productivity than gross farm product or real output. On the other hand, intercorrelation is more evident in the predictors of farm productivity.

Partial correlation coefficients

These are in table 5, part C. The significant predictor variables are those with non-zero partial correlations. Note especially the radical differences from the simple correlations shown in part A for research and extension. This demonstrates that the real effects of research and extension on output or on productivity cannot be determined by looking at general trends and likewise for other kinds of resource inputs. Another important point is the nonsignificance of persistent trends in output and productivity for the fairly long-term period 1929-1972. This suggests that variations in the use of selected basic farm resources or in the auxiliary inputs explain substantially all the output and productivity changes observed from 1929-1972. But the same is not true if we consider only the 25 years since 1948. There was actually a persistent downward time trend in productivity since 1948. The partial correlation of productivity with time was -0.36. This works out to a 3.37 percent expected annual decline in productivity if we were to ignore resource changes.

Elasticity coefficients

See part D in table 5. Significant predictors are again identified as those with non-zero elasticity coefficients. Negative elasticities were not precluded in the analysis since the main concern was to isolate tendencies

for output and productivity to change rather than to determine exact marginal resource productivities. The output elasticity coefficients sum to 1.380 for 1929-1972 and to 1.174 for 1948-1972 if we include only the basic land, labor and capital inputs. This tends to validate an hypothesis of increasing returns to scale in American agriculture. Increasing returns to scale are not as apparent in trends since 1948, however, and may have disappeared by 1972.

Sources of Growth in Output and Productivity

Here we come down to some empirical partial rates of growth or decline. Rates for the significant predictors of output and productivity are given in table 6, part B. They sum algebraically to the net rates of growth shown in part A. That is, from 1929-1972 there was an annual net increase of 1 percent in farm output and a 1.75 percent net increase in productivity. From 1948-1972 there was a 1.12 percent net increase in output and a 1.60 percent net increase in productivity or farm production efficiency.

To repeat, a partial rate of growth or decline is the product of (a) the average annual percent change in resource employment, and (b) its corresponding elasticity coefficient with respect to output or productivity. Part B in table 6 shows the resource change rates in conjunction with the partial rate, or net effect of the resource changes, as determinants of growth. The discussion will center primarily on the period 1929-1972.

Economic growth from 1929-1972

In part C of table 6 we repeat the resource change rates but in conjunction with the relative importance assigned to each relevant resource variable in explaining concurrent tendencies for growth and for decline.

For example, for the period 1929-1972, the migration of labor from agriculture was, input-wise, almost fully responsible for the inability of agriculture to achieve a faster rate of growth. And if we believe the data, the loss of hired agricultural workers, relatively speaking, was only about half as important an arresting factor on growth as the loss of family labor.

The factors stimulating growth are similarly identified. A steady accumulation of business inventories (primarily livestock) accounted for about 11 percent of the 'tendency' for real output to grow. Increased energy use accounted for 6 percent, but research and extension appear to have accounted for as much as 83 percent of the tendency for real agricultural growth from 1929-1972.

<u>Productivity gains from 1929-1972</u>

Refer again to table 6, part C. The forces explaining farm efficiency gains are shown to be quite different from those explaining agricultural growth. The loss of labor from agriculture appears to have accounted for about half (relative weight 50 percent) of the 'tendency' for efficiency to have decreased rather than have increased, with the loss of hired workers hurting efficiency somewhat more than the loss of family help and operators. The increased real investment in nonresidential farm buildings, statistically speaking, also seems to be associated with the tendency for efficiency to have declined (weight 18 percent). The remaining factor suppressing productivity is identified as public investment in natural resource development and conservation activities (weight 32 percent).

On the other side of the coin, five factors appearing to have contributed to increased farm production efficiency for the period 1929-1972 include: (1) decreased real capital investment in farm homes (relative weight 10

percent), (2) increased real capital investment in farm equipment (weight 10 percent), (3) increased real investment in business inventories (weight 5 percent), (4) electricity and petroleum energy inputs (weight 15 percent), and (5) public investment in agricultural research and extension (weight 60 percent).

Recap on Energy, Natural Resources and Research

The preceding sections on method and overall findings sufficiently describe the analysis and general results. This special section highlights some observations on agricultural growth and farm efficiency that seem warranted with regard to the auxiliary inputs of farm energy use, public natural resource investment, and public investment in research and extension activities. Policy recommendations are avoided because of the tentative nature of the analysis. Statistics supporting the discussion are in table 6. Range estimates will refer to the type of production function from which the effects of the three auxiliaries were assessed. Estimates pertinent to a functional estimator in which basic inputs were aggregated and which included the three auxiliaries are given as addenda in the table. These can be compared with other results in table 6 for a disaggregative estimator that included the same three auxiliaries.

Farm energy expenditures

Results with respect to farm expenditures for electricity and petroleum products suggest that energy use in agriculture has had a modest positive effect on total real output or economic growth in agriculture over the period 1929 to 1972. It has had a moderately stronger positive effect, however, on the efficiency of resource use on farms. Expenditures for energy increased an

average of about 4 percent per year during the period. This translates into an estimated partial growth rate of from zero to 0.27 percent or a theoretical gain in real farm output of between zero to 1/4 percent per year. The theoretical increase rate for productivity with regard to energy use was from 0.77 to about 1.06 percent. From 1929-1972, increased energy use accounted for between zero to 6 percent of the general tendency for output to increase and for 15 percent of the tendency for productivity to increase.

A different picture emerges for the period 1948 to 1972, during which farm energy expenditures increased by 1.1 percent per year. The corresponding theoretical or partial effect on total farm output appears to have been slightly negative (-0.15 percent). The effect on productivity was neutral. An overall observation is that while most of the agricultural benefits of greater energy use appear to have been obtained by 1948, current levels of use are not suppressing gains in agricultural productivity and are having only a very minor, if any, arresting effect on economic growth in agriculture.

Natural resource conservation and development

Results for public expenditures for natural resource development and conservation in agriculture indicate that, for the period 1929-1972, the investment contributed positively but not in any major way to the growth of real farm output. It appears to have depressed efficiency in the farm use of resources. The agriculture-related investment in natural resources by the public sector increased by an average of 7.25 percent per year from 1929-1972. This converts to a theoretical gain in total farm output of from zero to 0.52 percent per year, depending on the type of estimating relationship used. The theoretical effect on productivity ranged from zero to an annual decline of

1.59 percent. From 1929-1972, the public investment in natural resources and conservation in agriculture appears to have accounted for from none to 10 percent of the general tendency for real farm output to increase, but for from none to perhaps 1/3 of the general tendency for farm efficiency to have decreased.

For the period 1948-1972, the influence of public natural resource investment on output and productivity lessened considerably. The rate of increase in the public investment dropped to an average of 4.4 percent per year. There was no significant output-increasing or output-decreasing effect. The effect on farm productivity appears to have been on the order of from none to perhaps as much as 18 percent of the general tendency for farm productivity to have decreased rather than increased. This is a marked improvement when compared with the average for the period 1929-1972.

An important qualification on public investments in natural resources is that they mainly include developmental projects of long life, such as irrigation projects in the western States and, since about 1955, completed small watershed projects in all States. Conservation-type activities were added only at annual expenditure levels in the analysis, because many must be repeated frequently if not every year simply to maintain productivity. Also, certain runoff and sediment control practices are financed by the public sector for their nonagricultural benefits.

Agricultural research and extension

Findings with respect to public investment in agricultural research and extension are that it was the most important factor in real farm output in the United States having increased at a net average rate of 1 percent per year over the period 1929-1972 and in farm efficiency having increased netwise

at 1.75 percent per year. In constant dollar terms the investment in research and extension increased by 2.8 percent per year. This converts to theoretical or partial growth rates of from 3.5-4.0 percent for output, and from 3.7-4.0 percent for farm efficiency, depending on the type of functional estimator employed. From 81-83 percent of the general tendency for real farm output to have increased from 1929-1972 is explained by research and extension activities. They explain from 60-70 percent of the general tendency for farm productivity to have increased. The narrow range of these figures reinforces the judgment that research is a very identifiable input in the farm production process.

For the period 1948-1972, it appears that research and extension have been fairly neutral for economic growth in agriculture but have had increased importance with regard to farm efficiency. Since 1948 the average annual increase in the investment in these activities has run about 4 percent. This translates into no significant total output effect but into from a 6.5-7.3 percent theoretical gain in farm productivity. Whether we consider the related labor and capital inputs in the aggregate or separate them, about 78 percent of the general tendency for farm productivity to have increased from 1948 to 1972 is explained by research and extension. The remaining 22 percent appears about equally attributable to the increased real investment in farm equipment and business inventories.

The findings on research and extension must be interpreted with some caution. Industry-financed agricultural research and development was not considered in the analysis, primarily because comparable time-series information was not available. These activities have become very substantial in recent years and according to some estimates, not too well documented, rank equally with publicly financed research and extension (6, 23).

Further, a higher proportion of private research is in plant breeding, insect and disease control, and other production-oriented activities. So the growth and farm productivity effects attributed to public research and extension efforts are likely overstated, probably more so for the 25 years since 1948 than for the 44 years since 1929. An offsetting factor is that the public research expenditures include some activities not relating to farm production or efficiency. Examples are public forest management and certain other natural resource or foreign research activities supported in the U.S. Department of Agriculture.

The growth and farm efficiency consequences of research and extension should also be interpreted with regard to the particular manner of expressing the 'investment.' The investment level compared with total farm output and farm productivity for a given year was the total of annual research and extension expenditures for the prior 20 years, deflated to 1958 dollars. This 'capital-stock-of-knowledge' approach was taken to avoid complicated lag relationships in estimating how quickly new research information has been generated and used by farm operators. Although research lag and payoff-period questions have themselves been given some research attention (1, 6, 10), any systematic lagging of the production effects of research or extension expenditures at a national or aggregate level was not considered feasible in this study. A 20-year summation period, while quite arbitrary, gives a heavier weight to past than to current research investments, and also a heavier weight to the recent than to the not-recent past. Activities discontinued 20 years or more are dropped entirely. In this manner any residual effects on current production are subsumed in the effectiveness of current programs.

Research, Technology and Some Marginal Relations

This section deals very briefly with the question of how changes in agricultural technology have been associated with the changing use of resources and especially with public resources devoted to agricultural research and extension. Some comparative marginal products for the various basic and auxiliary resource inputs are also given, since changes in marginal returns over time help explain actual resource substitutions. The discussion is confined to the fairly long-term period 1929-1972.

Technology was not specifically examined but the analysis indicates, if we equate technology with residual time trends, that research and extension are manifested in technological change and directly rather than passively so. With research and extension not included in output and farm productivity estimators, time trend (technology) and farm capital investment almost completely, and equally, explain the tendency for increased real output or growth from 1929-1972. Only the trend appeared significant in explaining increased farm efficiency. When research and extension were included in the estimators for output, the influence of trend or technology disappeared. Regarding productivity, the influence of trend and capital investment both dropped sharply but remained significant.

Their behavior like close substitutes in explaining both output and productivity implies a definite causal relation between research and technology. Technological change doubtless spurs research to some extent but evidence for the reverse relation being dominant is much stronger. Public research and extension positively influenced the rate and character of technological change, general agricultural growth, and farm production efficiency. However,

the influence was not uniform for the entire period 1929-1972. We have shown previously how both growth and productivity were influenced to some extent by changes in other resource inputs.

Some impressions of how marginal returns for different resources differed and changed from 1929-1972 can be obtained from the following rates of change in resource use, estimated marginal products for 1929 and 1972 (in 1972 prices), and annual rates of change in the marginal products:

Resource inputs and annual percent change 1929-1972	Marginal product, in 1972 dollars		Annual pct. change 1929-1972
	1929	1972	
Total labor hours (-3.29)	$ 0.70	$ 4.00+	4.5
Family labor (-4.06)	0.45	4.00	5.2
Hired labor (-2.25)	1.00	4.05	3.2
Capital investment dollars (1.20)	0.08-	0.08	-0.1
Nonresidential structures (0.74)	0.75	0.80	0.3
Residential structures (-0.24)	0.00	0.00	0.0
Durable equipment (3.75)	-0.20	-0.06	2.8
Business inventories (1.03)	0.60	0.60	0.0
Farmland investment dollars (0.07)	-0.03	-0.04	-0.9
Energy expenditures (4.09)	2.40	0.65	-3.8
Natural resources investment dollars (7.25)	1.25	0.10	-6.3
Research investment dollars (2.84)	13.15	6.00	-1.8

For our purposes the marginal products above are averages of estimates separately obtained from aggregative versus disaggregative production-function estimators of total farm output. The aggregative/disaggregative marginal products for labor and inventories differed by quite a bit. Differences for the other inputs were not large, nor for any resource did the rate of change over time in its marginal product vary much from function to function.

Note that between 1929 and 1972 the marginal product of agricultural labor in the aggregate increased by a factor of about 4.7. The increase factor was about 7.8 for family labor and about 3.0 for hired labor. Corresponding annual rates of increase in marginal products were 4.5 percent for all labor, 5.2 percent for family labor, and 3.2 percent for hired labor.

In the aggregate the real rate of return or marginal product for capital was about the same in 1972 as it was in 1929-- around 8 percent. Marginal returns to investment in nonresidential farm buildings increased by 0.3 percent per year. For durable equipment they increased by 2.8 percent. In this case a 'statistically' negative marginal rate of return in 1929 had become less negative by 1972. The rate of return on inventory investment was about the same in 1972 as in 1929. Marginal returns to land were also negative, statistically, and appear to be declining further in relation to other basic farm inputs.

Marginal products for the auxiliary inputs of energy, natural resource investments, and research and extension all show substantial declines between 1929 and 1972. In 1972, for example, a $1 expenditure for energy at the farm level added at the margin 65 cents to gross farm product or total farm output, compared with $2.40 in 1929. This does not give us the current effect on farmer incomes, however, nor is it the average return with regard to total farm output.

For 1972 the marginal return on public investment in agricultural conservation and natural resource development works out in the analysis to about 10 cents of total farm output per dollar of investment, compared with about $1.25 in 1929. The annual decline has been about 6.3 percent. Public

natural resource conservation and development in agriculture has been a positive but a fairly minor and decreasing factor in the economic growth of the agricultural sector.

Marginal returns to research and extension in 1972 are estimated to have been about $6.00, compared with around $13.15 in 1929 (and about $10 in 1948). The annual decline has been on the order of 1.8 percent. These estimates are less than figures given earlier by Griliches and Evenson (10, 6). Griliches gives an estimate of $10 for 1959 in 1949 prices. My figure for 1959 in 1949 prices would be $7.15. The data support Evenson's recent judgment, cited in Wade (23), that returns to agricultural research, while they have been quite high in the past and are still impressive, are nonetheless declining.

Closing Comments

These are limited to general observations for the period from 1929 to 1972. Some are well supported in results of the analysis to date and others require further study.

The analysis shows rather clearly that agricultural research and extension activities have been more important to the economic growth and productivity of American agriculture than observed shifts in the use of basic farm resources or public investment in agricultural conservation and natural resource development. While natural resource programs have had a minor (and lessening) positive effect on growth they appear to have retarded farm production efficiency. Energy use in agriculture has contributed modestly to farm efficiency as well as to growth.

The positive and negative influences of capital accumulation on growth and productivity are less clearcut. Capital held as business inventories such as livestock has been (a) more important than investment in buildings or

equipment in explaining gains in total production, and (b) less important than buildings or equipment in explaining changes in efficiency. The increased real investment in equipment has increased production efficiency but does not appear to have stimulated total agricultural production. Relative to other resource changes, the increased real investment in nonresidential farm buildings has not affected total production and may have caused some production inefficiencies. The decreased real investment in farm homes has had no general effect on total agricultural production but appears somewhat correlated to gains in efficiency. This may be a statistical consequence of the declining number of farm operators and increasing returns to operator labor.

The most pointed conclusion concerns the growth and efficiency impacts of a reduced number of farm operators and hired workers. The loss of agricultural managers and other workers is shown in the analysis to have been the principal factor arresting both economic growth and farm production efficiency. It explains virtually all the 'tendency' for real output to decline between 1929 and 1972, recognizing that there was a net rate of growth in real output of about 1 percent per year. The loss of managers and other workers explained about half the 'tendency' for efficiency to decline, even though efficiency actually increased at a net rate of about 1.75 percent per year. Capital accumulation explains only about 11 percent of the dominating tendency for economic growth and 25 percent of the dominating tendency for increased farm production efficiency. Energy use accounts for 6 percent of the tendency for growth and 15 percent of the tendency toward increased efficiency. Conservation and natural resource investments account for perhaps 10 percent of the tendency for growth but for up to 1/3 of the tendency for efficiency to decline. Research and extension account for about 80 percent of the tendency for growth and 60 percent of the tendency for improved efficiency.

TABLES

Table 1--Farm energy expenditures and public expenditures for natural resource development and conservation in agriculture in the United States, for selected years from 1929-1972

Year	Annual farm energy expenditures 1/			Natural resource expenditures, in 1958 dollars		
	Fuel and oil in: current dollars	Total in current dollars	Total in 1958 dollars	Cumulative project investment	Annual conservation	Total investment
	2/ $ Billions	2/ $ Billions	$ Billions	3/ $ Billions	4/ $ Billions	5/ $ Billions
1929	0.315	0.325	0.452	0.666	na	0.666
1930	0.320	0.327	0.481	0.698	na	0.698
1935	0.266	0.275	0.465	1.064	na	1.064
1940	0.350	0.361	0.624	1.905	0.288	2.193
1945	0.578	0.596	0.890	3.579	0.435	4.014
1948	0.997	1.045	1.245	4.132	0.177	4.309
1950	1.179	1.229	1.430	4.917	0.345	5.262
1955	1.437	1.546	1.628	6.239	0.537	6.776
1958	1.448	1.592	1.592	7.870	0.573	8.443
1960	1.498	1.665	1.633	8.354	0.697	9.051
1965	1.717	1.877	1.841	9.942	0.804	10.746
1970	1.741	1.957	1.732	11.265	0.934	12.199
1971	1.815	2.040	1.744	11.485	0.898	12.383
1972	1.929	2.168	1.749	11.688	0.826	12.514

1/ Data derived from series in 1947-49 and 1957-59 dollars provided by Donald Durost of the Economic Research Service. All data in current dollars developed by use of the index of prices paid by farmers for motor supplies (1910-14) as published in Agricultural Statistics (21).

2/ Fuel and oil from 1929 to about 1948 accounted for around 97 percent of total farm energy expenditures, with electricity expense at 3 percent of the total. From 1948-72 the electricity component gradually increased--to about 11 percent of the 1972 total.

3/ Before 1955 includes capital investment in Federal (Bureau of Reclamation) irrigation projects and predominantly agricultural multipurpose projects and also expenditures for irrigation project rehabilitation and improvement, supplemental irrigation storage, etc. Since 1955 also includes Federal (Soil Conservation Service) investment in watershed protection under the Watershed and Flood Prevention Act of 1954.

4/ Includes Federal and State purchases of goods and services under the line item 'conservation of agricultural resources' in the national income and product accounts for the United States (22), starting in 1952. Data for 1936-51 developed from Agricultural Conservation Program figures in Agricultural Statistics (21). Data not available for years prior to 1936.

5/ Sum of cumulative project investment to date and annual conservation expenditures. The latter are not accumulated for this analysis because relatively few of the activities represent long-term investment.

Table 2--Public expenditures for agricultural research and extension in the United States for selected years from 1929-1972, in current and constant dollars and by source and use of funds

Year	Annual research and extension expenditures, in current dollars					Expenditures in 1958 dollars	
	Annual total	By source of public funds: State	By source of public funds: Federal	By use of public funds: State	By use of public funds: Federal	Annual total	Cumulative 20-yr. total
		1/	2/	1/	3/	4/	5/
	$ Millions	Percent	Percent	Percent	Percent	$ Millions	$ Billions
1929	38.1	21	79	31	69	103.3	2.003
1930	45.2	30	70	40	60	126.3	2.030
1935	35.6	28	72	42	58	96.5	2.102
1940	53.9	23	77	36	64	138.0	2.234
1945	64.9	28	72	37	63	126.4	2.337
1948	118.2	30	70	38	62	172.6	2.497
1950	149.4	30	70	38	62	207.4	2.666
1955	216.5	33	67	42	58	248.5	3.208
1958	306.2	32	68	41	59	306.6	3.703
1960	343.7	32	68	41	59	327.6	4.068
1965	359.5	44	56	56	44	299.7	4.917
1970	533.8	46	54	57	43	338.0	5.765
1971	582.8	46	54	57	43	344.7	5.906
1972	611.5	43	57	57	43	343.2	6.038

1/ Data on total State expenditures and source of public funds available to States obtained from annual reports of the State Agricultural Experiment Stations to the Cooperative State Research Service or predecessor agencies of the U.S. Department of Agriculture, which administers the various programs for States receiving Federal monies for research and extension. Data obtained with the assistance of Bruce F. Beacher and Bennett S. White of the Cooperative State Research Service.

2/ Data on total expenditures of the U.S. Department of Agriculture obtained from Jerome A. Miles of the Department's Office of Budget and Finance. Such totals include funds budgeted for USDA in-house research and extension activities and funds budgeted for disbursement to the States under Federal legislation.

3/ Federal component figured as the difference between total Federal expenditures as explained in note 2/ and State Experiment Station reports of monies received by disbursement of Federal funds through the U.S. Department of Agriculture. This difference is the approximate Federal expenditure for research and extension conducted by all USDA research and extension agencies.

4/ Current dollars converted to constant dollars by implicit price deflators for gross national product separately applied to Federal and State expenditures on a use basis.

5/ Total annual expenditures in constant (1958) dollars accumulated for the prior 20-year period.

Table 3--Agricultural output and productivity in relation to input resources and major demand factors for the United States for selected years from 1929-1972 1/

Variables and Data Sources 2/ (in constant 1958 dollars)	1929	1948	1958	1972 p	Annual Percent Change 1929-72 (44 years)	Annual Percent Change 1948-72 (25 years)
A. Output and Productivity						
Gross farm product, $bil. (22)	17.0	19.0	20.8	24.7	1.00	1.12
Output per unit input, 1958 = 100 (21)	59.5	84.3	100.0	122.4	1.75	1.60
B. Basic Farm Inputs						
Total labor inputs, bil. hrs.	23.2	16.8	10.5	6.5	-3.29	-4.24
Family labor, bil. hrs. (19)	14.0	10.5	5.1	3.4	-4.06	-5.09
Hired labor, bil. hrs. (19)	9.2	6.3	5.4	3.1	-2.25	-3.16
Total capital inputs, $ bil.	89.1	95.1	118.0	138.2	1.20	1.48
Nonresidental structures, $bil. (20)	19.3	16.0	19.4	22.8	0.74	1.43
Residential structures, $bil. (24)	37.9	36.4	36.0	33.8	-0.24	-0.35
Producers' durable equipment, $bil. (20)	13.9	22.2	38.9	53.6	3.75	2.65
Business inventories, $bil. (11)	18.0	20.5	23.7	28.0	1.03	1.33
Farmland (excl. buildings), $bil. (19)	83.2	54.5	60.5	63.8	0.07	0.63
C. Auxiliary Inputs						
Farm energy expenditures, $bil. 3/	0.5	1.2	1.6	1.7	4.09	1.10
Natural resource expenditures, $bil. 4/	0.7	4.3	8.4	12.5	7.25	4.44
Research and extension, $bil. 5/	2.0	2.5	3.7	6.0	2.84	4.06
D. Aggregate Demand Factors						
Total U.S. population, millions (19)	121.8	146.6	174.9	208.8	1.39	1.51
Per capita real income, dollars (19)	1,236	1,567	1,831	2,771	2.27	2.40
Agricultural exports, $bil. (21)	2.6	2.2	4.0	6.9	3.75	4.54

1/ 1929 included as the first year for which consistent and reasonably complete series of national income accounts data for items studied are available in published form. 1948 is included to roughly divide the period 1929-72 into two time periods, to cover the last 25 years, and also because it is the first year for which quarterly, monthly, and other specialized national income accounts data are regularly published. 1958 is included as the base year for converting current income, product, investment and other expenditure data to a constant dollar or comparable price basis. Data for 1972 are preliminary official or personal estimates.

2/ Parenthetical numbers refer to the list of References and cite the primary source of data for each of the output, productivity, input, or demand items. Various other sources were utilized in checking and developing complete data series for each item for the 44-year period from 1929-1972.

3/ Farm energy expenditures include electricity, fuels and lubricants. Data series provided by Donald Durost and Robert C. Otte of the Economic Research Service, USDA. More details in table 1.

4/ Includes all Federal and State expenditures for agricultural conservation programs, Federal expenditures for the program of the Bureau of Reclamation (excluding projects predominantly nonagricultural) and Federal expenditures for small watershed project development administered through the U.S. Department of Agriculture. Data compiled from various official reports, with most 1948-1970 data on conservation from reference (22). More details in table 1.

5/ See table 2 for source of data and more details on research and extension.

Table 4--Simple correlations of inputs and demand factors with U.S. agricultural output, productivity, and time for the period 1929-1972, for deviations from trend versus annual time series

Variables	Simple correlations--annual time series 1/			Simple correlations--trend deviations 2/		
	With gross farm product	With productivity	With time	With gross farm product	With productivity	With time
A. Output and Productivity Variables						
Gross farm product (output)	1.00	0.94	0.90	1.00	0.65	*
Output per unit input (productivity)	0.94	1.00	0.98	0.65	1.00	*
B. Basic Farm Input Variables						
Total labor inputs	-0.89	-0.95	-0.97	0.09	0.16	*
Family labor	-0.87	-0.94	-0.96	-0.06	0.04	*
Hired labor	-0.89	-0.93	-0.96	-0.17	0.20	*
Total capital inputs	0.91	0.95	0.96	0.31	0.14	*
Nonresidental structures	0.70	0.69	0.71	0.20	-0.04	*
Residential structures	-0.88	-0.93	-0.96	-0.11	0.16	*
Producers' durable equipment	0.87	0.95	0.97	-0.02	0.05	*
Business inventories	0.95	0.94	0.92	0.74	0.58	*
Farmland	0.17	0.10	0.08	0.24	0.12	*
C. Auxiliary Input Variables						
Farm energy expenditures	0.81	0.93	0.93	-0.24	0.19	*
Natural resource expenditures	0.86	0.95	0.96	-0.09	0.18	*
Research and extension	0.91	0.95	0.97	0.32	*	*
D. Aggregate Demand Factors						
Total U.S. population	0.91	0.98	0.99	0.20	0.07	*
Per capita real income	0.90	0.95	0.96	0.25	0.22	*
Agricultural exports	0.85	0.91	0.90	0.17	0.29	*

1/ Simple correlations of various variables with output, productivity, and time, with all variables in conventional units or index numberes for 1929-72.

2/ Simple correlations of 1929-72 deviations from trends for various variables with time per se and with output or productivity deviations from trend.

*. Practically zero. All are less than ± 0.01, which suggests the near absence of cyclical movements for the period 1929 to 1972.

Table 5--Partial correlations and elasticities for variables included in disaggregative estimators of U.S. agricultural output and productivity change from 1929-1972 and 1948-1972

Items and Variables	1929-1972		1948-1972	
	Output	Productivity	Output	Productivity
A. Simple Correlations for Research and Extension 1/				
1. Simple correlations in annual time series	0.91	0.95	0.96	0.98
2. Simple correlations in deviations from trend for period	0.32	0	0.22	0.63
B. Statistical Characteristics of Disaggregative Estimators				
1. Number of relevant predictor variables 2/	11	11	11	11
2. Number of significant predictors 3/	6	9	4	7
3. Coefficient of determination, R^2	0.940	0.987	0.920	0.986
4. Standard error of estimate for output or productivity (in log Y)	0.014	0.011	0.012	0.007
5. Mean intercorrelation coefficient, R(x)	0.397	0.442	0.192	0.307
C. Partial Correlation Coefficients for Relevant Variables	Coefficients with respect to output or productivity 3/			
1. Time trend	0	0	0.44	-0.36
2. Family labor	0.46	-0.31	0	0
3. Hired labor	0.53	0.61	0	0.39
4. Nonresidential structures	0	-0.45	0	0
5. Residential structures	0	-0.39	0	0
6. Producers' durable equipment	0	0.29	-0.19	0.42
7. Business inventories	0.50	0.54	0	0.61
8. Farmland	-0.24	0	0.30	-0.49
9. Farm energy expenditures	0.33	0.59	-0.21	0
10. Natural resource expenditures	0	-0.39	0	-0.43
11. Agricultural research and extension	0.52	0.55	0	0.61
D. Elasticity or Response Coefficients for Relevant Variables	Elasticities of output or productivity with respect to variables 4/			
1. Time trend (persistent percent change in output or productivity)	(0)	(0)	(0.80)	(-3.37)
2. Family labor	0.512	0.248	0	0
3. Hired labor	0.477	0.685	0	0.160
4. Nonresidential structures	0	-1.260	0	0
5. Residential structures	0	-2.910	0	0
6. Producers' durable equipment	0	0.174	-0.086	0.304
7. Business inventories	0.469	0.441	0	0.769
8. Farmland	-0.078	0	1.260	-2.070
9. Farm energy expenditures	0.065	0.259	-0.136	0
10. Natural resource expenditures	0	-0.219	0	-0.257
11. Agricultural research and extension	1.220	1.434	0	1.599

1/ Simple correlation coefficients indicate the degree of linear association of 1929-72 or 1948-72 output and productivity with research and extension expenditures, but with no allowance for joint association with any other variables. Perfect positive or negative simple correlation would be 1.00 or -1.00.

2/ Relevant independent variables included in the disaggregative estimator are those listed in sections C and D. Note the inclusion of trend per se as well as basic farm inputs or auxiliary variables, such as farm energy, natural resource, and research/extension expenditures.

3/ For significance the partial correlations in section C are required to be at least 0.14 or -0.14, implying at least a 2-percent reduction in the unexplained variance of output or productivity trend deviations gained by including the variable as a predictor of output or productivity deviations from trend. Partial correlation coefficients indicate the degree of linear association between deviations from 1929-72 or 1948-72 trends for each variable listed and deviations from trend for output and productivity, with allowance for the association of other listed variables. Perfect correlation (positive or negative) would be ± 1.00.

4/ Elasticity coefficients refer to the percent change in output or in productivity for each 1-percent change in the variables listed. Output or productivity vary directly with those variables having positive elasticity coefficients and inversely with variables having negative elasticities.

Table 6--Partial rates of growth in output and farm productivity for 1929-1972 and 1948-1972 1/

Variables Relevant to Growth or Decline	Annual percent change in resource variables 1929-72	Annual percent change in resource variables 1948-72	1929-1972 Output	1929-1972 Productivity	1948-1972 Output	1948-1972 Productivity
	Pct./yr.	Pct./yr.	Pct./yr.	Pct./yr.	Pct./yr.	Pct./yr.
A. Net Rate of Increase in Output and Productivity 2/	--	--	1.00	1.75	1.12	1.60
B. Partial Rates for Relevant Variables			Partial rates of growth or decline in output and productivity 3/			
Unexplained discrepancy--rate	--	--	-0.06	-0.13	-0.09	-0.41
--(percent)			(6)	(7)	(8)	(25)
1. Time trend	--	--	0	0	0.80	-3.37
2. Family labor	-4.06	-5.09	-2.08	-1.00	0	0
3. Hired labor	-2.25	-3.16	-1.07	-1.54	0	-0.51
4. Nonresidential structures	0.74	1.43	0	-0.93	0	0
5. Residential structures	-0.24	-0.35	0	0.70	0	0
6. Producers' durable equipment	3.75	2.65	0	0.66	-0.23	0.81
7. Business inventories	1.03	1.33	0.48	0.45	0	1.02
8. Farmland	0.07	0.63	-0.01	0	0.79	-1.30
9. Farm energy expenditures	4.09	1.10	0.27	1.06	-0.15	0
Addendum: farm energy	(4.09)	(1.10)	(0)	(0.77)	(-0.16)	(0)
10. Natural resource expenditures	7.25	4.44	0	-1.59	0	-1.14
Addendum: natural resources	(7.25)	(4.44)	(0.52)	(0)	(0)	(0)
11. Agricultural research and extension	2.84	4.06	3.47	4.07	0	6.50
Addendum: research & extension	(2.84)	(4.06)	(4.08)	(3.66)	0	(7.27)
C. Partial Importance for Relevant Variables			Percent importance in explaining growth or decline 4/			
1. Time trend	--	--	0	0	50	-54
2. Family labor	4.06	-5.09	-66	-20	0	0
3. Hired labor	-2.25	-3.16	-33	-30	0	-8
4. Nonresidential structures	0.74	1.43	0	-18	0	0
5. Residential structures	-0.24	-0.35	0	10	0	0
6. Producers' durable equipment	3.75	2.65	0	10	-61	10
7. Business inventories	1.03	1.33	11	5	0	12
8. Farmland	0.07	0.63	-1	0	50	-20
9. Farm energy expenditures	4.09	1.10	6	15	-39	0
Addendum: farm energy	(4.09)	(1.10)	(0)	(15)	(-24)	(0)
10. Natural resource expenditures	7.25	4.44	0	-32	0	-18
Addendum: natural resources	(7.25)	(4.44)	(10)	(0)	(0)	(0)
11. Agricultural research and extension	2.84	4.06	83	60	0	78
Addendum: research & extension	(2.84)	(4.06)	(81)	(70)	0	(78)

1/ Generally based on disaggregative estimators including energy, natural resources and research as auxiliary inputs.

2/ Net rates of increase are the algebraic sum of unexplained discrepancies and the partial rates in part B associated with significant predictors; e.g., those variables in part B with nonzero partial rates of output or productivity growth or decline.

3/ Partial rates for time trend is the trend itself as an annual rate. Partial rates for resource variables are the product of annual rates of change in the resource variables (cols. 1 or 2) and corresponding elasticities given in part D of table 5. Zeros are for the variables relevant but not significant predictors for the periods studied. Partial rates for energy, natural resources and research obtained from aggregative rather than disaggregative estimators are shown as addenda and in parentheses. They do not use the elasticities in table 5.

4/ Numerical percentages are of total tendencies for growth (+) or for decline (-). That is, each ± partial rate in part B is expressed either as a percentage of the sum of all positive partial rates or as a percentage of the sum of all negative partial rates. Unexplained discrepancies are excluded from these calculations. Addenda for energy, natural resources and research are for aggregative estimators including them.

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